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eRD16: Forward/Backward Tracking at EIC using MAPS Detectors

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Abstract:

This report describes progress towards the conceptual development of tracking stations with silicon-sensors near the collision vertex to detect the scattered electron and produced secondary hadrons at forward and backward angles with respect to the beam directions in the period between July and December 2017. The main focus is on disks with thinned-silicon sensors (MAPS) with the goal to arrive at physics-driven sensor specifications, the overall geometrical arrangement of the forward/backward disks, disk layout, conceptual arrangement of services, and integration with central barrel tracking subsystems. Part of this work is being pursued in collaboration with eRD18, which focuses on mid-rapidity tracking and sensor development.

1. Introduction and Motivation

The US nuclear physics program plans to build an Electron Ion Collider to study the gluonic structure of nucleons and nuclei [1]. The facility will be built at Brookhaven National Laboratory as an upgrade to the Relativistic Heavy Ion Collider accelerator or at the Thomas Jefferson National Accelerator Laboratory as an upgrade to the CEBAF facility. The EIC is scheduled to come online in the 2030 timeframe.

The overall goal of eRD16 is to provide a conceptual design for precision endcap trackers for the EIC utilizing Monolithic Active Pixel Sensors (MAPS). Achieving this goal requires work in several directions, including the integration with a silicon barrel tracker. The eRD16 and eRD18 groups are collaborating to carry out this work over the next several years.

The scattering region along the direction of the *electron* beam gives access to the gluon-dense ("small-x") nuclear environment through leptonic and hadronic observables with energies below the EIC *electron* beam-energy. Tracking in this region serves both leptonic and hadronic momentum measurement. The momentum measurement, together with the energy measurement using electromagnetic calorimetry, is key to the identification of the scattered electron through measurement of E/p. Unobserved losses of the scattered electron's energy, e.g. bremsstrahlung, introduce a bias in Bjorken-x, typically towards smaller values. The scattering region along the direction of the *hadron* beam is of considerable scientific interest as well. Here, new insights are anticipated for example in the partonic energy-loss mechanism(s) in cold nuclear matter. Particle energies along the direction of the forward-going hadron beam are typically considerably higher than those along the forward-going electron beam at an EIC. In general, tracking in the forward directions imposes considerable challenges in the 1.5 and 3T solenoidal fields that are under consideration for the general purpose EIC detector concepts. Combined, these aspects point to a need to develop low-mass, well-integrated, barrel and endcap silicon trackers.

2. Progress on simulations

At the EIC Generic R&D meeting in July 2017 and as part of the proposal that was submitted at that time, eRD16 presented results from an initial set of simulations aimed at a conceptual layout/design of pixel tracking stations in the forward and backward scattering regions at a future EIC.

A project scientist (Lai) is utilizing the tools developed at BNL specifically for EIC simulation. He has performed a number of simulations for the 3T solenoid of 2m length and 1.2m radius and the symmetric detector geometry of the forward and backward silicon disk trackers envisioned in the BeAST detector concept [2]. These studies have focused so far on reproducing several of the baseline results and on detector variations with different pixel sizes and different numbers of disks.

A number of studies have been performed using a toolset that was developed originally for tracking studies for the ILC detector concepts [3] with UC Berkeley undergraduate students (Velkovsky and DeGraw). The ILC toolset performs a simplified simulation of the detector measurements, based on a helix track model and taking into account multiple scattering, followed by full single track reconstruction from digitized hits using a Kalman filter. Initial results have been obtained with this set of tools for both the BeAST detector concept and for the detector concept based around the 1.5T BaBar magnet [4].

Separately, LBNL-LDRD funds have made it possible to attract a postdoctoral researcher (Lomnitz) who has pursued event-generator development related to the EIC as his main activity. These LDRD funds have made it possible also to consider aspects of a low-mass inner silicon barrel tracker for mid-central rapidities at an EIC (Lomnitz, Sichtermann), which are related to but otherwise distinct from our eRD16 efforts.

As this report is being prepared, several of the above studies are being reproduced and an internal note summarizing the results will be prepared. The initial outcomes point to endcap arrays in both forward directions with 5—7 disks. The disks will closely surround the beam pipe and extend over more than 1m along the beam axis so as to be able to track most of the charged particle's curvature in the solenoidal field. Our scans of pixel size indicate that 20 to 30 micron square pixels are sufficient for momentum measurement at an EIC for the different solenoidal magnetic fields and detector configurations that are being considered. Figure 1 (left) shows representative relative momentum resolutions versus pseudo-rapidity for endcap tracker configurations with 5 and 7 disks spanning approximately 1 m. All 5 or 7 disks are used to reconstruct the track for η = 3. The step-like behavior in the resolution towards smaller and larger η has its origins in the particle track traversing fewer disks because of the track angle and the ~19 cm outer and ~2 cm inner radii of the disks in these simulations, as well as their locations along the beam axis between ~25 cm and ~121 cm from the nominal interaction point. At the highest and lowest pseudo-rapidity values on these curves, the tracking uses only three of the five or seven disks to measure momentum; for these extreme pseudo-rapidities, the disk configurations thus have no redundancy for momentum (curvature) measurement. Figure 1 (right) shows the relative momentum resolution from a scan for different square pixel sizes versus momentum for standalone tracking with a 7 disk configuration in a 3T solenoidal field.

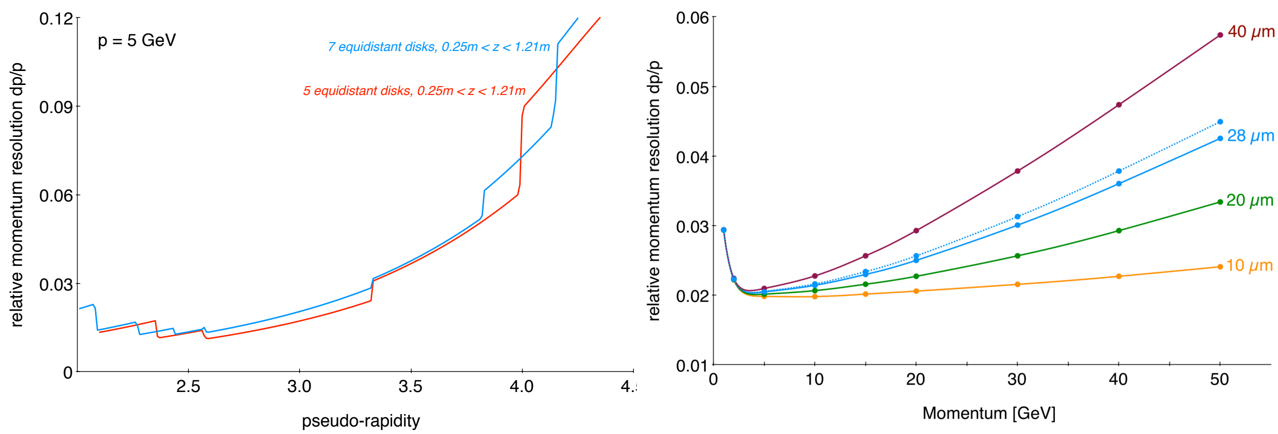

Figure 1: (left) The pseudorapidity dependence of relative momentum resolution at the interaction vertex for standalone tracking with 5 and 7 disks spanning 0.96m in a 3T solenoidal field at a fixed (total) momentum, p = 5 GeV. The sensor's pixel size is 28 microns in these simulations and the disk thickness is χ_0 = 0.3%. (right) Relative momentum resolution for standalone tracking with the same configuration of 7 equidistant disks at a fixed pseudorapidity η = 3 for different pixel sizes, as indicated.

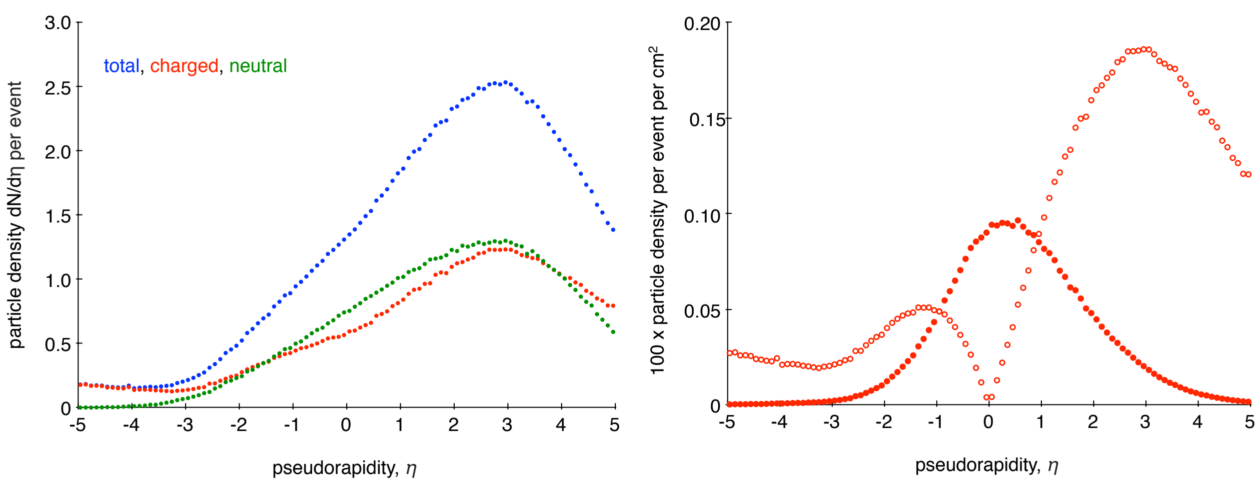

Figure 2: (left) Particle densities dN/dη versus η per collision event for 10 GeV electrons and 100 GeV protons for Q^2 > 0.1 GeV^2. (right) The corresponding charged particle densities along (filled symbols) and orthogonal (open symbols) to the beam axis at a distance of 10cm.

An important further characteristic of the proposed MAPS sensors is the duration of their signal integration in relation to the anticipated collision rates. This (effective) integration time is typically several μs. Since the EIC beam crossing frequency will be 10MHz or higher, the sensors will integrate over multiple crossings. For anticipated EIC luminosities of $10^{33\text{-}34}cm^{-1}s^{-2}$, the total anticipated collision rates are at the level of 50-500kHz, well below the beam crossing rate. Multiple collisions per crossing are thus unlikely to occur at the EIC, unlike at the LHC. Nevertheless, multiple collisions will occur within the sensor effective integration time. The resulting hits/tracks need to be disambiguated with external fast(er) detectors.
Figure 2 (left) shows a representative distribution of charged and neutral particles, together with their sum, for collision events with a 10 GeV electron and 100 GeV proton beam from pythia-based simulations within the BNL-EIC framework. Positive pseudorapidity is defined along the direction of the forward going hadron beam (adopting the HERA convention). In Figure 2 (right), the charged particle density is shown across a 1 cm^2 surface positioned along (filled symbols) or orthogonal to (open symbols) the beam axis at a fixed radius of 10 cm and at a position along the beam axis corresponding to the indicated pseudo-rapidity. The track (hit) density at the surface of such an imaginary sensor vanishes towards large (absolute) pseudorapidities in the case of a barrel configuration and at mid-rapidity for a disk configuration; the densities are equal at 45 degrees with respect to the beam.
As part of the proposal for the ongoing cycle, we developed and performed initial standalone simulations in which tracks traversing the forward disks, generated independently according to the anticipated rate profiles, are 'anchored' in time to hits in the (fast) large-area forward GEM disks that are part of the BeAST baseline design in both the forward electron and the hadron going directions (these hits were assumed to originate from the charged tracks produced in a single collision event only). This development has been extended to include hits from (random) sensor noise, to slower (less idealized) track anchoring detector layers than in the initial studies, and to the central detector region. In the upcoming period we will extend these studies to anchoring to the considerably more involved case of drifting tracks, such as those from the BeAST-TPC, and aim to transition also for these studies from standalone simulations to full simulations.

3. Personnel

Forward disk conceptual design simulation efforts have been carried out by Project Scientist Yue Shi Lai, ES, and several younger scientists. Lai's EIC effort focuses on simulations within the BNL-developed EICroot framework. UC Berkeley undergraduate students Ivan Velkovsky and Winston DeGraw have been supported by eRD16 funds to participate in fast-simulations towards endcap trackers for the BeAST concept. LBNL-LDRD funds have supported separate efforts, distinct from but with synergies with eRD16, by postdoctoral researcher Michael Lomnitz

4. Closing comments

The development of truly low-mass trackers requires advances on multiple fronts, including low-mass conductor cables and cooling. These and other aspects continue to be of key interest to eRD16. For the ongoing period though, as described in the proposal, we have chosen to defer most of these aspects until the concepts for a practical sensor layout on forward disks and its integration with a barrel tracker are further advanced. Through the SULI/BLUR program at LBNL it has been possible to make some progress on cooling. Silicon trackers have traditionally been cooled with liquid circulating through part of the support structure or by air-flow across the sensors. Cooling through micro-channels incorporated in the sensor is being researched for application at the ILC, currently still with high material impact but also with ambitious goals. Prior R&D performed by the LBNL physics and engineering divisions, and successful SBIR rounds with an industrial partner have led to the development of porous foams with high thermal conductivity opening the possibility in specific cases to provide cooling by flowing air directly through the silicon support structure. As part of this prior R&D, tests were performed for stave configurations and a cooling model was developed. We have adapted this model to wedge-like structures that could become a candidate support structure of a forward disk (Velkovsky). The initial and preliminary finding is that rectangular and trapezoidal structures have similar characteristics, irrespective of the direction of the airflow. We will follow up on this study if/when a suitable, new student can be attracted through the SULI/BLUR or a similar program. No new progress was made, or promised, on the development of low-mass conductors specific to forward disks during this reporting period.

As noted in an earlier report, LBNL identified the EIC as a focus for near term strategic institutional support. This has led to LDRD funding in FY17 and FY18 for effort distinct from, but with synergies with, the eRD16 efforts discussed here. Several of the eRD16 co-authors are part of this LDRD, in collaboration with other colleagues at the Laboratory. The focus for FY18 is emphasizing more of the physics studies of the original LDRD proposal (and, consequently, deemphasizing some of the instrumentation development in FY17 that has made studies possible pertaining to the barrel region). These efforts are likely to result in one or more publications in the foreseeable future.

References

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